A Dynamic MAC Protocol for WCDMA Wireless Multimedia Networks

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***Abstract*—Existing MAC protocols like TDMA and 802.11 have many disadvantages for scheduling multimedia traffic in CDMA wireless networks. Our objective is to develop a dynamic MAC protocol for WCDMA networks to avoid congestion and improve the channel utilization and throughput of the bulky real-time flows. In this paper, we propose to develop a dynamic MAC protocol for wireless multimedia networks. In the design, we combine the merits of the CSMA, TDMA MAC protocols with WCDMA systems to improve the throughput of the multimedia WLAN in a cellular environment. We use these MAC protocols adaptively, to handle both the low and high data traffics of the mobile users. It uses multiple slots per frame allowing multiple users to transmit simultaneously using their own CDMA codes. By simulation results, we show that our proposed MAC protocol achieves high channel utilization and improved throughput with reduced average delay under low and high data traffic.**

***Index Terms*— Wideband Code Division Multiple Access (W-CDMA), MAC protocol, Direct Sequence Spread Spectrum (DSSS), Time division multiple access (TDMA), Carrier Sense Multiple Access (CSMA)**

I. INTRODUCTION

A. Wideband Code Division Multiple Access (W-CDMA)

W-CDMA is 3G mobile telecommunications networks which have now turned into an air interface standard. This has become the basis of Japan's NTT DoCoMo's FOMA service. W-CDMA has turned out to be the most-commonly used member of the UMTS family and many of the times used as an alternative for UMTS. [1]. It is a direct sequence spread spectrum (DSSS) system. The bandwidth of any data is spread to a much wider bandwidth and this reduces the power spectral density. There are two main types of wideband CDMA schemes: network asynchronous and network synchronous. [2, 3]

1. Network asynchronous schemes - In network synchronous schemes, the base stations are synchronized to each other within a few microseconds. There are three network asynchronous proposals: W-CDMA1 in ETSI and ARIB, and TTA II wideband CDMA in Korea.
2. Network synchronous scheme – This scheme proposed by TR45.5 (cdma2000) is considered by Korea (TTA I). The ITU radio transmission technology description of different wideband CDMA schemes can be found.

The key features related to W-CDMA are [4]

- Supports both FDD (frequency division duplex) and TDD (time division duplex) modes
- Inter-cell asynchronous operation
- Employs coherent detection on uplink and downlink based on the use of pilot symbols
- To increase capacity and coverage, Multi user detection and smart antennas can be used.
- Multi code transmission and variable mission: on a 10 ms frame basis
- Uses adaptive power control based on Signal to interference ratio.
- Multiple types of handoffs between different cells including soft handoff, softer handoff and hard handoff.

B. WCDMA Vs CDMA

CDMA is a technique for spread spectrum multiple access. In CDMA, locally generated code runs at a much higher rate than the data to be transmitted. Data to be broadcasted is simply logically XOR (exclusive OR) added with the faster code.[5] At the contrary, the wide-band CDMA (W-CDMA) technology has been appeared as the major air interface for 3G wireless systems which provides a transmission rate of 144Kbps to 2Mbps. These have enabled multimedia services like the broadband wired networks. The technology can support services with higher rate when is measured up with the narrow-band CDMA. W-CDMA is also flexible to distribute multimedia traffic but a new medium access control protocol (MAC) is needed in order to manage packet access resourcefully in wideband CDMA wireless networks. [6]

C. Issues in W-CDMA

As per [7], the issues related in W-CDMA can be given as the following;

- Pilot Pollution – It is a scenario in which a mobile station receives numerous pilot signals with strong reception levels, but none of them is dominant enough that the mobile can track it. The signals are on the similar frequency and thus interface with one hand.

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- HO problem – Inter-frequency of HO consists of compressed mode. But the problem with compressed mode for the network is the lower spreading ratio. A spreading code with a low spreading ratio openly uses more capacity from the corresponding cells. Thus increase in compressed slots, wastes the capacity of these cells.
- SHO Parameter - SHO parameter may increase the overall system interference level, but in the same way it decreases the system capacity. A SHO also consumes more data transmission capacity in the network.
- Hierarchical cells - Hierarchical arrangements in the W-CDMA is to assign each hierarchy level on a divergent frequency. This produces adjacent channel interference (ACI). This also proposes a mobility effects along with capacity requirements of mobile station.

D. MAC Layer of WCDMA

The channel structure of W-CDMA consists of logical, transport and physical channels. The physical layer proposes services to the medium access control (MAC) layer via transport channels. Transport channels are depicted by "How" and "With what" characteristics the data can be transferred. The key characteristic of the MAC layer is to select suitable transport format to be used as a function of the data rate**.** [8] The MAC layer consists of three logical entities; MAC-b, MAC-c/sh and MAC-d. The MAC-b handles the broadcast channel (BCH). The MAC-c/sh handles the common channels and shared channels: paging channel (PCH), forward link access channel (FACH), Random access channel (RACH), uplink common packet channel (CPCH) and downlink shared channel (DSCH). The MAC-d is responsible for handling dedicated channels (DCH) allocated to a UE in connected mode [9].

The main feature of the MAC layer includes [9]:

- Mac layer forms Mapping between logical channels and transport channels.
- The ciphering and the traffic volume monitoring are done by MAC Layer.
- Selection of appropriate Transport format (TF) for each transport channel, depending on the instantaneous source rate.
- Executing of the switching between common and dedicated transport channel is based on a switching decision derived by Radio resource control (RRC).
- MAC handles service multiplexing for common transport channels and also for dedicated channels.
- Priority handling between data flows of one User equipments (UEs) as well as between UE. The former is achieved by selecting 'high bit rate' and 'low bit rate' Terminal equipments (TEs) for different data flows.
- Priority handling between UEs by means of dynamic scheduling for common and shared downlink transport channels FACH and DSCH.

In our research work, we propose to develop dynamic MAC protocol for wireless multimedia networks. In the design, we have combined the merits of the CSMA, TDMA MAC protocols with WCDMA systems to improve the throughput of the multimedia WLAN in a cellular environment. We have used these MAC protocols adaptively, to handle both the low and high data traffics of the mobile users. It uses multiple slots per frame allowing multiple users to transmit simultaneously using their own CDMA codes.

II. Related works

V.Sumalatha et al [10] proposed a congestion control mechanism for CDMA based IP-RAN networks. Here they implement congestion avoidance using the mechanism of router control. An AQM-RED is implemented to realize Router control mechanism to maximize network capability while maintaining good voice quality. The performance of implementing system using AQM-RED is evaluated with Drop tail AQM method. CDMA is implemented with AQM RED and has seen how the congestion is avoided and the throughput is increased.

Uthman Baroudi et al [11] proposed an adaptive call admission/congestion control policy. The policy is based on window measurement, by assessment of the status of the buffer at the base station under the hybrid TDMA/CDMA access scheme. The window- measurement effectively maintains the required QoS, particularly the blocking probability, call establishment delay and cell error rate. They inter-relate the physical limitations of the base station, instantaneous buffer conditions call and burst level traffic and end to end bit error performance in one queuing problem.

Hai Jiang et al [12] proposed MAC scheme which can achieve bit-level QoS, low overhead, accurate channel and interference estimation along with high bandwidth efficiency. The scheme also has the potential to support packet-level QoS and service differentiation. They also proposed a distributed MAC scheme to address these limitations, where active receivers determine whether a candidate transmitter should transmit its traffic or defer its transmission to a later time.

Junshan Zhang et al [13] proposed a multi-access interference (MAI) process in CDMA networks which estimates time-varying channel conditions and the bursty-ness of data traffic and opened a new dimension to understand the corresponding MAI temporal correlation structure. The predictive MAI temporal structure is exploitable for adaptive resource allocation to achieve efficient interference management, which is the key to achieve high spectral efficiency in CDMA systems.

Liang Xu et al [14] proposed a class of dynamic fair scheduling schemes based on the generalized processor sharing (GPS) fair service discipline, under the generic name code-division GPS (CDGPS). The CDGPS scheduler uses both the traffic characteristics in the link layer as well as the wideband CDMA physical layer to perform fair scheduling on a time-slot basis, by using a dynamic rate-scheduling approach other than the conventional time-

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scheduling approach. A credit-based CDGPS (C-CDGPS) scheme is proposed to further enhance the utilization of the soft capacity by trading off the short-term fairness.

Jennifer Price et al [15] proposed a cross-layer approach to optimal rate assignment in multi sector CDMA networks. The algorithm was a "one-shot" algorithm; which implies that it combines the MAC and transport layer protocols to control interference and congestion simultaneously. They investigated the dual-based algorithm in which the delay associated with addition of intermediate queues at each wireless source provides the necessary information for coordinating MAC and transport layers.

III. Dynamic MAC Protocol

A. Existing Protocols

A channel-access scheme is related with a multiple access protocol and control mechanism, known as media access control (MAC). This protocol deals with issues such as addressing, assigning multiplex channels to different users and avoiding collisions. [16] There are many proposed multiple access protocols for wireless networks as well as many MAC protocols that have been developed for wireless voice and data communication networks. Typical examples include the time division multiple access (TDMA), code division multiple access (CDMA), and contention-based protocols like IEEE 802.11 [17]. There are four basic types of channel access schemes namely; Frequency division multiple access (FDMA), Time division multiple access (TDMA), Code division multiple access (CDMA), Space division multiple access (SDMA). There are many works which are based on the above schemes and many hybrid approaches among them. Most of the hybrid approaches like [18, 19] are based on CSMA and TDMA. But they have many disadvantages like;

The disadvantages of CSMA are:

- Even though there are many advances in technology, carrier sensing is still a vital problem for radio networks due to the hidden terminal problem. Due to severe channel fading in indoor environments and the utilization of directional antennas, dependable carrier sensing is extremely difficult.
- According to many research works, CSMA protocol is unstable

The disadvantages of TDMA are:

- Since TDMA on the uplink demands high peak power in transmit mode, it shortens battery life for the mobile handsets.
- For matched filtering and correlation detection for synchronizing with a time slot,

TDMA requires a significant amount of signal processing.

B. DS-SS (CDMA) Based MAC Scheme

In wideband system, the entire system bandwidth is made available to each user and is many times larger than the bandwidth required for transmitting information. Such systems are known as"Spread Spectrum" (SS) systems. There are two fundamental types of SS: Direct Sequence Spread Spectrum (DS-SS) and Frequency Hopping Spread Spectrum (FH-SS). In DS-SS, the user's data is spread using a Pseudo-Random sequence code (PN code) and further modulated and then transmitted. The received signal after despreading, resolves into multiple signals with different time delays. A RAKE receiver can recover the multiple time-delayed signals and can combine them into one signal, providing an inherent time diversity receiver with lower frequency of deep fades. When many mobile users transmit data to a common base station, then each user will use a unique PN code to spread his data for transmission. The PN codes of all users are orthogonal. It is this correlation property of the codes that makes it possible for the extraction of the desired signal at the receiver. By multiplying the information-bearing signal $b(t)$ by the spreading code $c(t)$, each information bit is chopped into a number of small time increments commonly called as chips. Thus transmitted signal $m(t)$, may be expressed as:

$$m(t) = c(t)\,.\,b(t) \qquad (1)$$

which is a wideband signal. The received signal $r(t)$ contains the transmitted signal $m(t)$ plus the additive interference $i(t)$. The interference signal contains MAI (Multiple Access Interference) and fading and any other external interference signals. Therefore,

$$r(t) = m(t) + i(t) + n(t) = c(t).\ b(t) + i(t) + n(t) \qquad (2)$$

where, $n(t)$ is Additive White Gaussian Noise (AWGN) in the receiver. To receive the original signal $b(t)$, the received signal $r(t)$ is multiplied by the code which was used in the transmitter. Therefore, the demodulated output $z(t)$ at the receiver is given by

$$z(t) = c(t).\ r(t) = c2(t).b(t) + c(t).\ i(t) + c(t).n(t) \qquad (3)$$

Since, $c2(t) = 1$ (the autocorrelation property of the PN code),

$$z(t) = b(t) + c(t).i(t) + c(t).n(t) \qquad (4)$$

C. Hybrid Approach

As per the above statement, these have many disadvantages using either CSMA or TDMA singularly with WCDMA systems. In our approach, we propose to develop an dynamic MAC protocol for wireless multimedia networks. In our technique, the merits of the CSMA, TDMA MAC protocols are combined with WCDMA systems for enhancing the throughput of the multimedia WLAN in a cellular environment. In order to handle low and high data traffics of the mobile users, we considered MAC protocols adaptively. For allowing multiple users to transmit with the help of their own CDMA codes, multiple slots per frame are used by them. Taking all these merits into consideration in our approach, we develop a dynamic MAC protocol for WCDMA networks for avoiding

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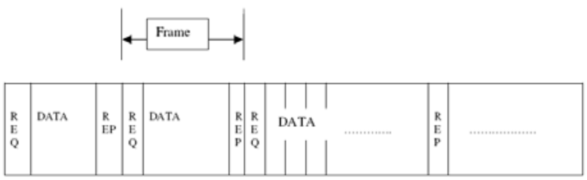
congestion and to enhance the channel utilization and throughput of the bulky real-time flows.

While describing the access system we take only one mobile cell into account in which there are M active nodes(or users) that generates messages to be transmitted to another node. This type of network is termed as an infrastructure networks as per the IEEE 802.11 standards where the base station controls all the nodes within the cell. Two kinds of links are possible in this model.

1. Uplink: this demonstrates data transmission from mobile station MS to BS.
2. Downlink: this describes the data transmission from BS to MS.

In a topological aspect, the base station is positioned for good propagation condition. The location of the portables is uncertain and varying. The wireless propagation conditions have a strong impact on a choice of a suitable multiple access protocol.

1) WCDMA Scheduling



Where,

REQ –Request
REP - Response

M1 M2 M3 ………….. MN

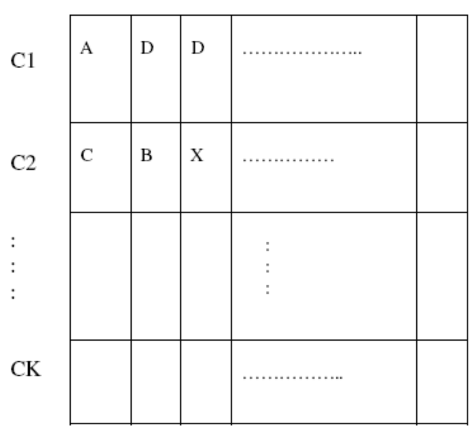


Figure 1. Hybrid WCDMA Scheduling

Where,

C1, C2….CK: CDMA Codes
M1, M2…MN: Mini Slots

The time is divided into fixed size frames in the proposed protocol. A frame has N time slots for the purpose of communication. The two special types of slots in each frame are the Request (REQ) and the Reply (REP) slots which are separated into mini slots. The mini slots of REQ are used in the uplink and mini slots of REP are utilized in the downlink. The REP mini slots are modified to a matrix of data slots and CDMA codes (refer Figure 1). The data slot and CDMA for a user are assigned by a scheduling algorithm (explained in section III.D) and this data is send to the user as a REP signal by the BS.

A REQ signal along with some control information's is send to BS by the user which is ready for transmission. The scheduling algorithm of BS enables the user to get a REP signal about the data slots and CDMA codes. Enabling the user to transmit the data together with the processing of the requests of the nodes and the scheduling is done with the help of the REP signal. In our dynamic work, each terminal transmits at the time slots during which it is allowed to transmit using its own code sequences. Hence some terminals are allowed to transmit in a simultaneous manner at the time slot with acceptable Bit Error Rate (BER).

The REP is divided into mini slots, each holding information of the corresponding data slot in the next frame. Each mini slot is further divided into grid, where grid is equal to the maximum number of nodes that can transmit data simultaneously in a data slot. Each of these grids is initialized with a code which the scheduler allocates to the node which succeeded in getting a reservation for that slot. We assume that each node generates messages with an arrival rate λ which is Poisson distributed. The message length of each node is exponentially distributed. A node cannot generate a new message until all packets of the current message are transmitted completely. A node which has generated a message in the current frame cannot try to access the data slots in the same frame.

2) WCDMA Contention

In this dynamic MAC, traffic is classified as Real time (RT) and Non Real time (NRT) and prioritized as High and low, respectively. For the high priority data traffic, a node can be in one of two modes: low data traffic (LDT) or high data traffic (HDT). A node is in HDT only when it receives a High Contention (HC) Message (HCM) from a two-hop neighbor within the last T period. Otherwise, the node is in LDT. A node sends an HCM when it experiences high contention due to high data traffic. Each node calculates the data traffic (DT) (to be explained in section III.D) to calculate the contention. If DT is more than a threshold value DT_{th}, then the nodes will send a HCM. In LDT, any node can compete to transmit in any slot, but in HDT, only the owners of the current slot and their one-hop neighbors are allowed to compete for the channel access. In both modes, the owners have higher priority over non-owners. If a slot does not contain an owner or its owner does not have data to send, non-owners can transmit their data in this slot.

D. Scheduling Algorithm

For the random access protocol, we use the M/M/n/n/K Markov model by obtaining the steady state equation as:

$$\vec{x} A = O \tag{5}$$

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where A is the generator matrix, O is a null matrix and $\vec{x}$ is a steady state probability vector and it is equal to

$$\vec{x} = \{x_0, x_1, x_2 \cdots x_n\} \tag{6}$$

For this Markov chain, the recurrent non-null and the absorbing properties are satisfied. $'K'$ is the number of users and the number of data slots are $'n'$. The average number of packets served by the system is calculated as:

$$PA = \frac{(K\mathrm{T})\sum_{i=0}^{n-1}\binom{K-1}{i}T^i}{\sum_{i=0}^{n}\binom{K}{i}T^i} \tag{7}$$

Here, T is the offered traffic to the system with the arrival rate and T is given by;

$$T = \frac{\lambda}{\mu} \tag{8}$$

Where, λ is Poisson distribution and the service rate and μ is the exponential distribution.

The probability of the packet success rate PSR is calculated as ;

$$PSR = \sum_{k=0}^{c}\sum_{j=0}^{n}(1-xj)(1-Berr(k)) \tag{9}$$

here $''c''$ is the active number of CDMA codes allocated to the active users in a data slot and the steady state probabilities are given as;

$$x0 = \frac{1}{\sum_{i=0}^{n}\binom{K}{i}T^i} \quad \text{and} \tag{10}$$

$$xj = \binom{K}{j}T^j x0 \tag{11}$$

and $Berr(k)$ is the BER value, which is given by the relationship as;

$$Berr(k) = \frac{1}{2}erfc\left(\sqrt{\frac{Eb}{No + \frac{2}{3}Eb(\frac{k-1}{\beta p})}}\right)$$

Where,
k = Number of active user.
βp = Processing gain of the spectrum.
Eb = Energy per bit in joules
No = The two-sided psd in Watts/Hz

E. Data Traffic Calculation

Each node calculates the traffic by using the traditional way to calculate the system capacity for data traffic (DT), which is given by;

$$DT = \left[\frac{\beta p}{SIR}\right] \times \frac{1}{1+\kappa} \times P \times \frac{1}{\Phi} \times \beta a \tag{12}$$

Where,
βp and βa = the processing gain by spectrum spreading and gain due to sector antenna respectively.
SIR = Signal to interference ratio
κ = The interference from other nodes
P = The power control factor
Φ = The voice/data activity factor.

Every neighbor calculates the traffic to deduce the contention.

IV. Experimental Results

A. Simulation Setup

In this section, we simulate the proposed dynamic MAC (DMAC) protocol for WCDMA cellular networks. The simulation tool used is NS2 [20] which is a general-purpose simulation tool that provides discrete event simulation of user defined networks. In the simulation, mobile nodes move in a 600 meter x 600 meter region for 50 seconds simulation time. Initial locations and movements of the nodes are obtained using the random waypoint (RWP) model of NS2. All nodes have the same transmission range of 250 meters. The simulation parameters are given in table I.

Table I. Simulation Parameters

Area Size	600 X 600
Number of Cells	2
Users Per Cell	20
Slot Duration	2 msec
Radio Range	250m
Frame Length	2 to 8 slots
Frame Duration	1 second
CDMA codes	2 to 5
Simulation Time	50 sec
Routing Protocol	AODV
Traffic Source	CBR, VBR
Video Trace	JurassikH263-256k
Packet Size	512 bytes
MSDU	2132
Transmission Rate	1Mb,2Mb,…5Mb
No. of Users	2,4,6,8 and 10

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TABLE II. WCDMA SYSTEM PARAMETERS FOR DATA USERS

Bandwidth	Received Signal power	$\eta = \frac{N_z}{W_t}$	SNR	Bit rate for data	P.G.
5 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.158866= -7.99 dB	144kbps	34.7
				384kbps	13
10 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.079433= -11 dB	144kbps	69.4
				384kbps	26
20 MHz	$7.9433*10^{-11}$ w = -101 dB	10^{-16}	0.0397165= -14 dB	144kbps	138.8
				384kbps	52

B. Performance Metrics

We compare our proposed DMAC protocol against the normal TDMA and 802.11 MAC protocols.

The performance is mainly evaluated according to the following metrics:

Channel Utilization: It is the ratio of bandwidth received into total available bandwidth for a traffic flow.

Throughput: It is the throughput received successfully, measured in Mb/s.

Average End-to-End Delay: The end-to-end-delay is averaged over all surviving data packets from the sources to the destinations.

The performance results are presented in the next section.

C. Results

A. Effect of Varying Transmission Rates

In the first experiment, the transmission rates are varied as 1,2,3,4 and 5Mb and measured the channel utilization, end-to-end delay and throughput.

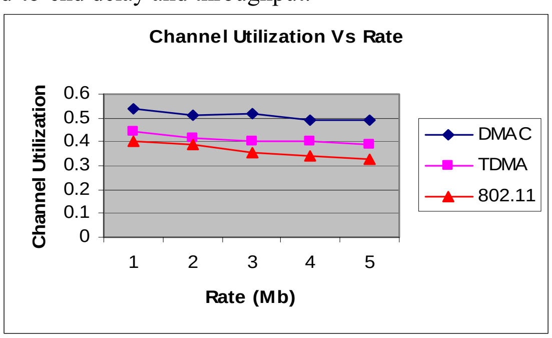

Figure 2. Channel Utilization Vs Rate

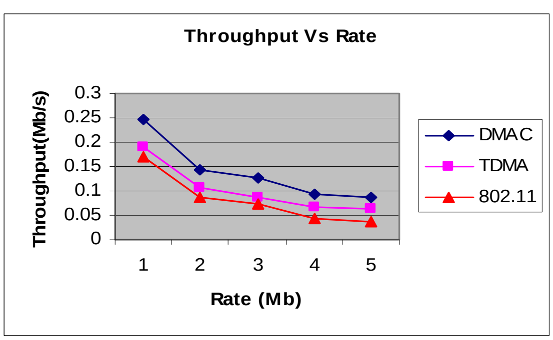

Figure 3. Throughput Vs Rate

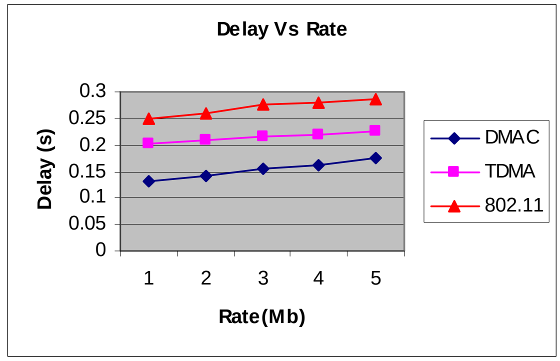

Figure 4. Delay Vs Rate

When the traffic rate is increased, more traffic flows will contend and hence fair utilization of channel will be decreased. It can be seen that from Figure.2, the channel utilization gradually decreases a little when the rate is increased. Figure.1 shows the channel utilization obtained for various rates. It shows that DMAC has better utilization than the TDMA and 802.11 protocols.

Figure.3 shows the throughput obtained with the proposed DMAC protocol compared with TDMA and 802.11 protocols. From the figure, it can be seen that the throughput for all the protocols are drastically decreased, when the rate is increased. It shows that the throughput of DMAC is more than the TDMA and 802.11, as rate increases.

Figure.4 shows the delay occurred for various rates. From the figures, it can be observed that the delay increases gradually when the rate is increased. It shows that the delay of DMAC is significantly less than the WTTP scheme TDMA and 802.11 protocols, since it has the adaptive contention resolution mechanism.

B. Effect of Varying Sources

In the second experiment, the number of sources is varied as 2, 4, 6, 8 and 10 and measure the channel utilization, throughput and end-to-end delay.

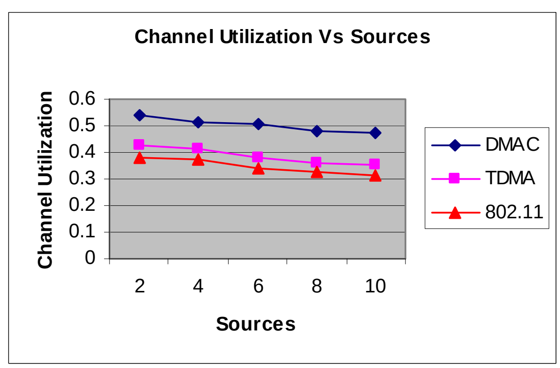

Figure 5. Channel Utilization Vs Sources

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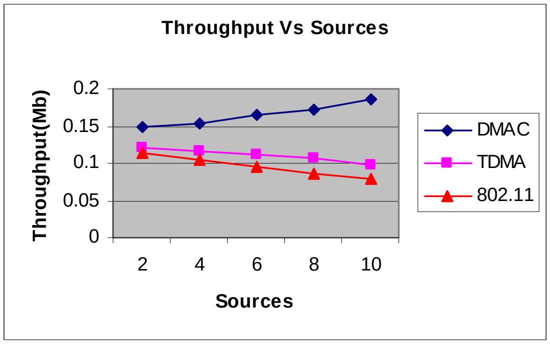

Figure 6. Throughput Vs Sources

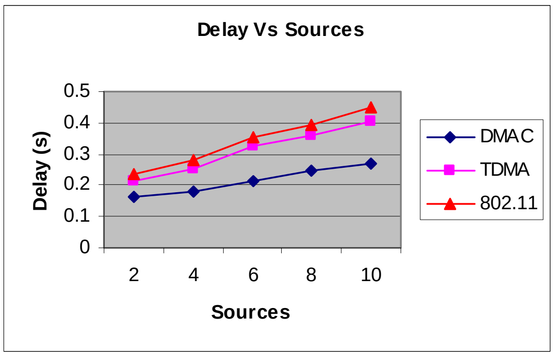

Figure 7. Delay Vs Rate

When the traffic sources are increased, more stations will contend for the channel and hence fair utilization of channel will be decreased. It can be seen from Figure.5, the channel utilization gradually decreases a little when the number of sources is increased. It shows that DMAC has better utilization than the TDMA and 802.11 protocols.

Figure.6 shows the throughput obtained with the proposed DMAC protocol and other MAC protocols. From the figure, it can be seen that, the throughput of both TDMA and 802.11 are decreased, when the sources are increased. But it shows that the throughput is more and increases for DMAC, because it supports multiple users.

Figure.7 shows the delay of traffic occurred, when the sources are varied. . From the figure, it can be observed that the delay increases gradually when the sources are increased It shows that the delay of DMAC is significantly less than other protocols.

V. Conclusion

In this paper, we have developed a dynamic MAC protocol for WCDMA wireless multimedia networks. In this design, we have combined the merits of the CSMA, TDMA MAC protocols with WCDMA systems to improve the throughput of the multimedia WLAN in a cellular environment. We have used these MAC protocols adaptively, to handle both the low and high data traffics of the mobile users. It uses multiple slots per frame allowing multiple users to transmit simultaneously using their own CDMA codes. Hence our dynamic MAC protocol for WCDMA networks avoids congestion and improves the channel utilization and throughput of the bulky real-time flows. By simulation results, we have shown that our proposed MAC protocol achieves high channel utilization and improved throughput with reduced average delay under low and high data traffic. As a future work, we will include a power control mechanism to this protocol.

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